M.Sc. in Civil and Structural Engineering

3rd Semester and Master's Thesis Ideas 2010

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AALBORG UNIVERSITY
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Aalborg University
Department of Civil Engineering
School of Civil Engineering

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May 2010

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M.Sc. in Civil and Structural Engineering: 3rd Semester and Candidate Project Ideas

The following pages contain a list of project ideas proposed by the scientific staff at the Department of Civil Engineering, Aalborg University, and a number of companies. Most of the project ideas in this catalogue may form the basis for long and short candidate projects as well as regular 3rd semester projects at the M.Sc. programme in Civil and Structural Engineering.

Each project description provides a brief overview of the purpose as well as the main activities. Further, a weighting between theoretical analysis, experimental work and computer modelling has been proposed. Usually, this weighting can be changed slightly in accordance with the wishes of the students. The contact persons listed will act as primary supervisors. Questions regarding details about each proposed project should be asked to these persons. Further, other ideas for projects may be discussed with a potential supervisor.

The preferred group size is two to four students. In the interest of students as well as supervisors, single-student projects are generally not recommended.

As a final remark, a signed project plan must be handed in one month after the initiation of the project. This project plan must contain information about the project, in particular regarding the educational goals of the project. These must be defined in accordance with the Master Curriculum as well as the Study Programme Guide for the M.Sc. Programme in Civil and Structural Engineering at the School of Civil Engineering, Aalborg University. A document master for the project plan is available at the homepage of the School of Civil Engineering: www.bsn.aau.dk.

Aalborg, 10 May 2010 Johan Clausen, *semester coordinator*

Detailed Calculation of Kinematics in Nearly Breaking Irregular Waves

Purpose: Kinematics of nearly breaking and breaking waves are not very well understood. Nevertheless, accurate estimations of wave kinematics are very important for estimation of loads on marine structures in shallow water. This can easily be demonstrated for example by looking on run-up on a pile, cf. Fig. 1.

Fig. 1: Large scale testing of loads on wind turbine access platforms.

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One of the project goals IS to improve calculation models for loads on secondary structures like, for example, access platforms for offshore wind turbines and boat landings. These calculations can be performed in CFD but an alternative is a local Fourier approximation, leading to an approximation of the stream function in irregular waves. This makes it possible to calculate wave kinematics in waves that are not symmetrical around the wave crest.

Main activities: Implementation of code in MatLab or other programming language is the main activity and thus good programming skills are needed. The main activities are:

- Look at newly performed model tests to quantify importance of wave shape on run-up on piles and loads on secondary structures
- Implementation of Local Fourier approximation code in MatLab or other programming language
- Application of method to newly performed tests. Additional verification tests can be performed in the laboratory if needed.
- CFD computations can be included if time permits.

Contact person: Thomas Lykke Andersen

Theory: ☒☒☒ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

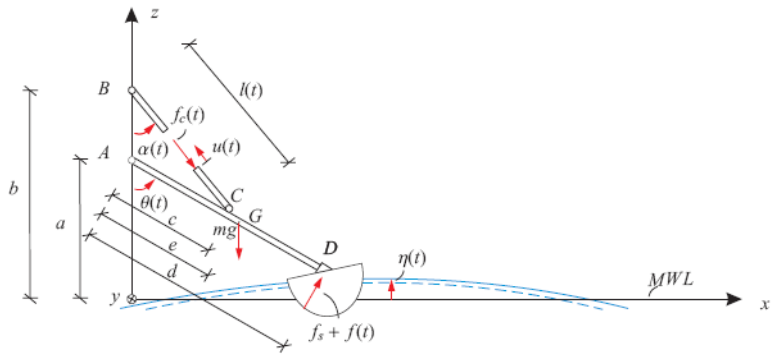
Projects on Breakwater Design

Purpose: A number of different projects are available within breakwater design. We can discuss different possibilities within caisson breakwaters and rubble mound breakwaters depending on main interest area.

The main activity would for most projects be laboratory model tests but also projects with detailed computer modelling are available.

Contact person: Thomas Lykke Andersen

Nonlinear Stochastic Control of a Wave Energy point Absorber in Irregular Waves



Purpose: The point absorber approach is based on a floating body of a size that is small compared to the dominating wave length. When a point absorber is left uncontrolled, the simplest but poorest way to optimize the *Power-Take-O*ff (PTO) is by tuning the natural frequency to the local sea state statistics of the site where the device will be deployed. Many control approaches for optimizing the power developed with a WEC have been proposed and the Latching approach is the simplest and most investigated of these methods. The latching control strategy enforces the correct phase shift between the water level and device displacement by locking the device at the extremities of its oscillatory cycle. This is implemented by locking the device displacement when velocity is equal to zero and releasing it a certain time later. The optimum power achievable from this method is intrinsically non-continuous, although it can be calculated iteratively. Alternatively, reactive control involves application of forces to the device that are in phase with both displacement and acceleration. Both latching and reactive control can develop significantly improved off-resonance power by using knowledge of the incoming wave. The discontinuities related to the latching control provides practical problems at the mechanical realization. In the present project a non-linear stochastic control of the point absorber is suggested. The performance index is taken as the maximum of the expected value of the power output from the absorber. The control force on the piston arm is based on a conventional, collocated PID feedback control on the motion of the piston arm.

Main activities:

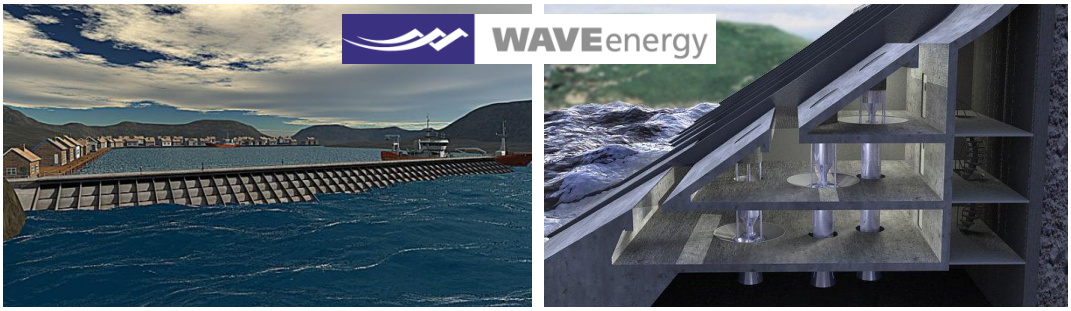
- Getting knowledge point absorber theory
- Knowledge of control methods
- Evaluation of non-linear stochastic control of a point absorber

Contact person: Søren R.K. Nielsen, Poul Henning Kirkegaard, Peter Frigaard

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐

SSG Breakwater Wave Energy Device

Purpose: The Sea-wave Slot-cone Generator (SSG) is a wave energy converter of the overtopping type initially designed to be installed near shore and on breakwaters for coastal and harbour protection, as illustrated below. The device is being developed by the Norwegian company WaveEnergy AS, in cooperation with Aalborg University. The device accumulates the overtopping water in a number of reservoirs at a higher level than average sea water level, for efficient capture of the energy in incoming waves. The potential energy in the stored water is, on its way back to the sea, converted into electricity, as it passes through specially designed low head turbines. The project will focus on one or more of the following key performance aspects of the geometrical design of the SSG – energy capture, structural loadings, overtopping over the whole structure, wave reflections from the structure. The goal is to provide design tools based on laboratory tests, supported by theoretical and numerical calculations, for each of the investigated aspects.



Main activities: The work involved in this project can be divided into the following items:

- Planning of experimental setup – wave conditions, scaling, instrumentation.
- Carrying out the laboratory testing in the wave tank.
- Data analysis.
- Generalize results and compare to existing information from literature on related issues.
- Apply obtained results in a case study.

The project can be carried out as a 3rd semester, half year master or one year master project.

During the project a close contact to the developer WaveEnergy A/S is possible.

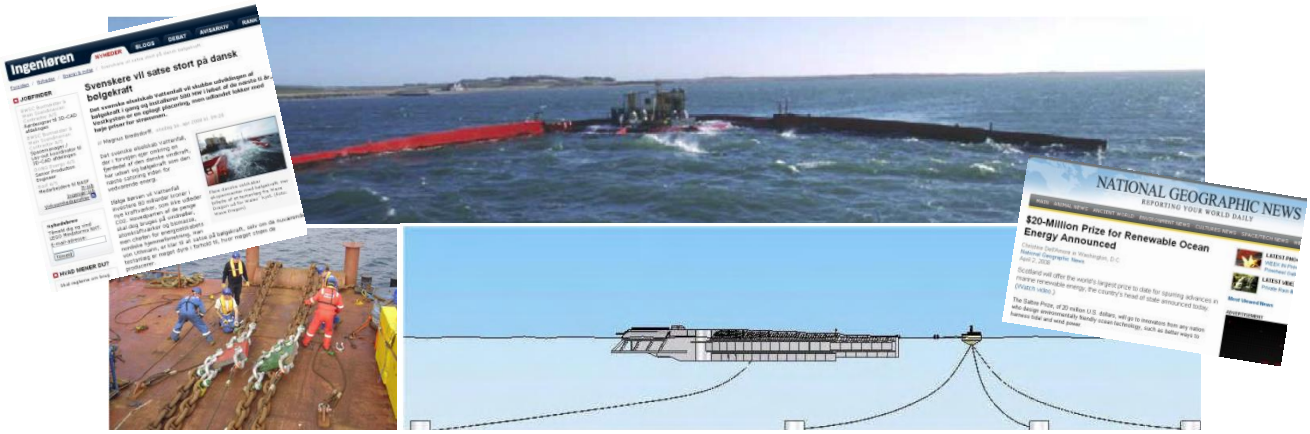
Contact person: Jens Peter Kofoed

Theory: ☒☒☐ **Experimental Work:** ☒☒☒ **Computer Modelling:** ☒☐☐
(Depending on preferences - the project can be focused to fit your interests)

This is one among a large space of options to work within the field of wave energy utilization – if you are interested in participating in the development of the renewable energy industry of the future, please drop by and we will formulate the project that fits your specific interests!

Mooring of floating Wave Energy Converters

Purpose: Currently, the race towards developing the most cost efficient wave energy converters is dramatically picking up in speed. One important element of this development is the design of cost efficient mooring systems. In the proposed project focus will be on generic design and comparison of different mooring layouts for a slack moored floating wave energy device. This could be an overtopping based device, such as the Wave Dragon, or other device types, eg. LEANCON, DEXA, Pelamis, etc. Traditionally, this type of mooring systems is of the catenary type, using heavy steel chains attached to anchor blocks at the sea bed. However, other options exist, e.g. using weights and floaters on lighter moorings lines. This option should also be explored and compared in terms of cost efficiency.



Main activities: The work involved in this project can be divided into the following items:

- Design basis – device, location, environmental conditions (wave, wind, current), soil conditions, etc.
- Design criteria – loadings on mooring system, performance requirements, etc.
- Design of mooring systems – different alternatives. Involves analytical/ numerical calculations and/or laboratory tests.
- Design of anchor points – different alternatives gravitation/piling/suction buckets. Involves analytical/numerical calculations and/or laboratory tests.
- Estimation of economics of the various alternatives.
- Conclusions – pros and cons of the alternatives.

The project can be carried out as a 3rd semester, half year master or one year master project.

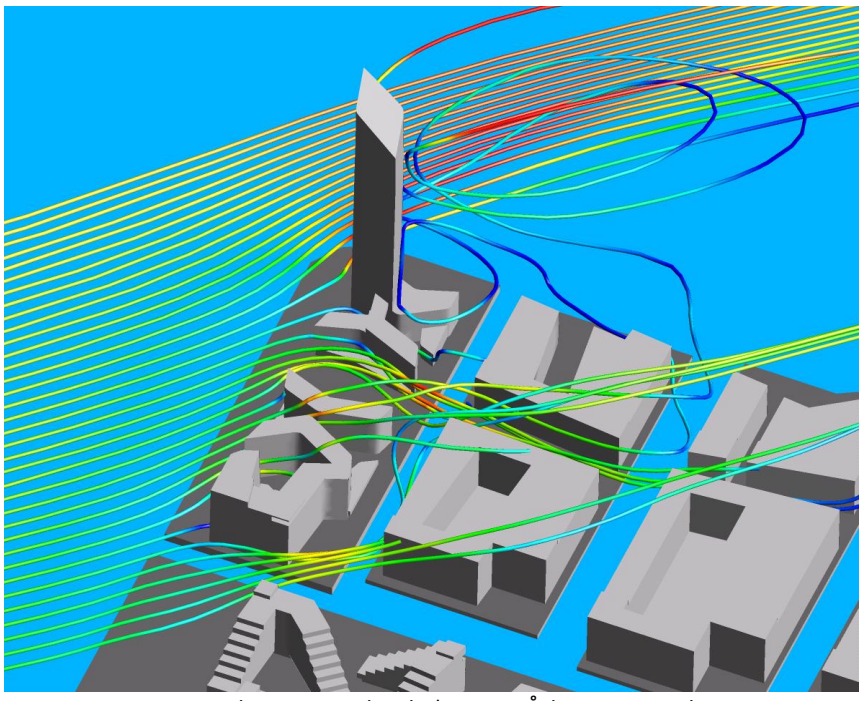
Contact person: Jens Peter Kofoed

Theory: ☒☒☐ **Experimental Work:** ☒☒☐ **Computer Modelling:** ☒☒☐
(Depending on preferences - the project can be focused to fit your interests)

This is one among a large space of options to work within the field of wave energy utilization – if you are interested in participating in the development of the renewable energy industry of the future, please drop by and we will formulate the project that fits your specific interests!

Wind comfort modelling around tall buildings

Purpose: Tall buildings create their own local wind climate. In certain circumstances this can result in amplification of both the mean wind velocity and of the turbulence. This can generate very uncomfortable or even unsafe wind situations at ground level. The challenge is to combine the vision of the architect with methods of the civil engineer. CFD models are a strong tool for evaluating local wind climate. However, the results from a CFD model can be difficult to translate into variables which correspond to comfort levels and safety levels for pedestrians. The purpose of this project is to use CFD to study interaction between wind around tall building and operational criteria for comfort and safety for pedestrians.



Streamlines around Light*House, Århus, Denmark

Main activities: This project will involve field, laboratory and computational methods. The main activities are:

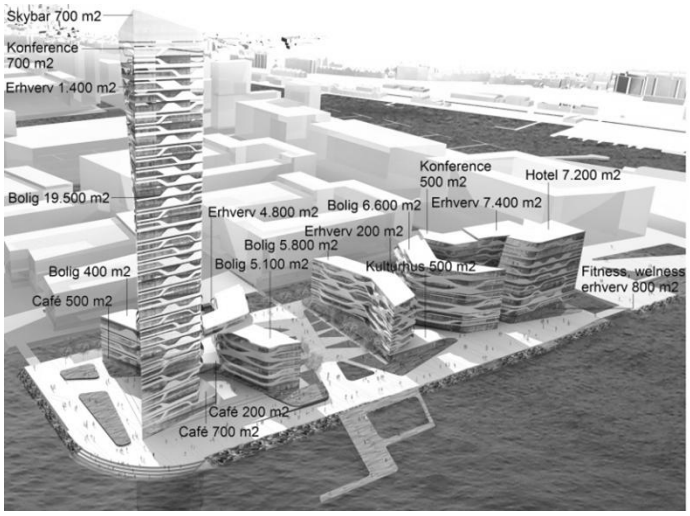
- CFD modelling of existing tall buildings
- Comparison between CFD simulations and field measurements (local tall buildings)
- Scale experiments in water flume to generate reference data.
- Evaluate different turbulence models with respect to comfort criteria
- Test different methods to avoid uncomfortable wind climate.

Contact person: Michael R. Rasmussen

Theory: ☒☐☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☒

Fundering af Light*house på Århus Nordhavn

Purpose: Light*house er et bolig- og erhvervsområde, der skal opføres som led i et større byggeprojekt, hvor den nuværende containerterminal på Nordhavnen i Århus skal omdannes fra industriområde til byområde. De eksisterende pier på havnen skal omdannes til en række kunstige øer, og på den yderste ø ud mod Århus Bugt skal bebyggelserne, der under ét kaldes Light*house, opføres. Områdets varetegn skal være et Danmarks højeste hus, 142 meter, placeret yderst på den anlagte ø ud mod Århus Bugt. Under hele området skal der anlægges et underjordisk parkeringsanlæg. En af de geotekniske udfordringer i forbindelse med byggeprojektet bliver at undersøge, hvordan højhuset kan funderes under hensyntagen til anlæggelsen af parkeringskælderen samt påvirkninger fra de omkringliggende bygninger. Projektet gennemføres i samarbejde med Grontmij | Carl Bro



Main activities: Dette projekt tager udgangspunkt i højhusbyggeriet Light*house på Århus Nordhavn Hovedfokus er hvordan styrke og deformationsegenskaber for den tertiære ler, der på lokaliteten findes til 70 - 90m dybde, kan bestemmes ud fra geotekniske forsøg og hvordan disse resultater kan anvendes i 3D finit element modellering.

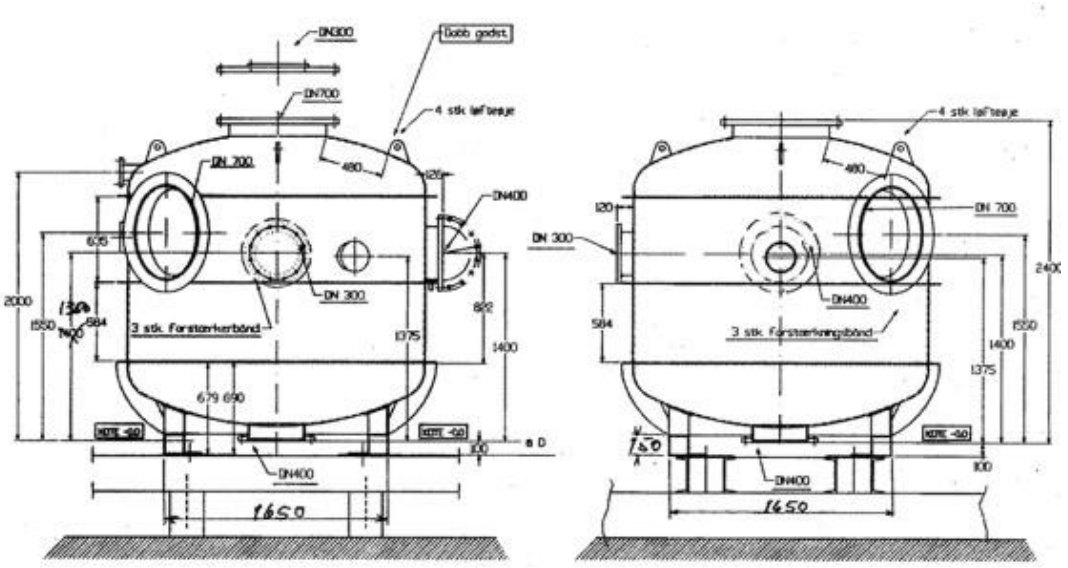
- Jordens egenskaber analyseres ud fra boreprøver samt CPT-boringer foretaget på projektlokaliteten. I forbindelse med boringerne er der foretaget vingeforsøg, og der er optaget en række prøver hvorudfra vandindhold, kalkindhold, pH-værdi samt konsistensgrænser er bestemt.
- Intakte prøver fra boringerne analyseres vha. konsolideringsforsøg , **c**onstant **r**ate of **s**train-forsøg (CRS-forsøg) og triaxialforsøg.
- Alle de foretagne undersøgelser anvendes til at bestemme, hvordan jordens egenskaber varierer med dybden. Forsøgsresultaterne anvendes til at kalibrere de numeriske beregningsmodeller.
- Der gennemføres 3D Plaxis beregninger af sammenspil mellem funderingen af højhuset og parkeringskælderen.

Contact persons: Lars Bo Ibsen, Benjamin Nordahl Nielsen

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

Bøttefundamentets styrke- og deformationsegenskaber ved cyklisk belastning

Purpose: De kræfter der virker på vindmøller, transient og cykliske i natur, giver anledning til elastiske oscillationer og muligvis til liquefaction af sandet inde i bøtten. Sådan sand liquefaction vil sandsynligvis føre til fuldstændige bæreevnesvigt, hvorfor liquefaction skal undgås.



Main activities: Forholdene, der kan føre til sådanne tilstande, skal undersøges og fastlægges ved eksperimenter. En forsøgstank indeholdende faciliteter til udlejring af jorden samt mulighed for statisk og transient og cyklisk belastning er udviklet i dette forår ved laboratoriet for fundering, Aalborg Universitet, se figuren. Tanken ønskes gennem dette projekt at blive gjort fuld operationel. Tankens belastningssystem er opbygget således, at det kan benyttes til cykliske udmattelsesforsøg. Herved kan risikoen for liquefaction undersøges:

Resultaterne af disse forsøg sammenholdes med resultaterne fra de statiske forsøg. Herved kan det evalueres, om den varierende belastning har indflydelse på fundamentets bæreevne, stivhed samt plastiske deformationer.
Den elastiske opførsel under cyklisk belastning er vigtig for interaktionen med tårnet, og dette skal kortlægges ved hjælp af eksperimenter, analyse og beregning på baggrund af elasticitetsteori udfra de udførte forsøg noget til sidst.

Contact person: Lars Bo Ibsen

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

Bøttefundamentets styrke- og deformationsegenskaber ved installation i ler

Purpose: 3-D numerisk simulering af forskellige typer af bøttefundamenter installeret i ler foretages. Deres anvendelighed til offshore vindmøller undersøges med henblik på forståelse af deres opførsel under normale og ekstreme laster når den funderes i ler.

Main activities: Resultater fra en række modelforsøg (fra afsluttet afgangsprojekt) skal simuleres numerisk og sammenlignes med resultater fra analytiske modeller. I de numeriske simuleringer vil der blive arbejdet med en avanceret konstitutiv model for jorden, Single Hardening modellen, og det tilsigtes at jord/struktur behandles så realistisk som muligt. Denne model er implementeret i det kommercielle finite element program 3D PLAXIS som eksternt defineret materialemodel. Materialeparametre findes fra triaksialforsøg udført på jordprøver fra de relevante offshore lokaliteter og fra kalibrerede CPT-forsøg udført ved siden af borehullerne.

De simulerede bøttefundamentforsøg er de ovenfor beskrevne modelforsøg og de forsøg. Disse inkluderer udrænede forsøg, i hvilke bøtterne er påvirket af moment, horisontale og vertikale kræfter. De numeriske analyser er i stand til at simulere ændringen i størrelse og form af brudfladen i H-M/D planet, svarende til de eksperimentelle observationer.

Contact person: Lars Bo Ibsen

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

Advanced probabilistic geotechnical site assessment for offshore wind farms

Purpose: Ved opførelse af store vindmølleparker til havs udgør funderingen ikke kun en betragtelig del at anlægsudgiften 25 - 35%, men er også den del af projektet, der indeholder de største usikkerheder. For at reducere disse usikkerheder foretages et omfattende geotekniske undersøgelsesprogram, hvilket kræver en stor investering tidligt i projektforløbet. Kravet til minimering af fundamenternes deformationer gør, at det altid er anvendelsesgrænsetilstanden, der bliver dimensionsgivende, dvs. at de elastiske parametre styrer designet. Ved in-situ forsøgene bestemmes de plastiske materialeparametre, der anvendes til brudanalyse, med stor nøjagtighed, mens de elastiske parametre bestemmes med stor usikkerhed. Der er derfor i dag en konflikt mellem de parametre, der driver designet, og det man får ud af de udførte in-situ forsøg. Fokuset er i dag forkert og bør drejes mod en bedre bestemmelse af de elastiske parametre. Dette projekt fokuserer på at udvikle en in-situ test metode, der sikre bedre bestemmelse af de elastiske designparametre. Ideen er at udvikle en "intelligent sandsynlighedsbaseret teststrategi", der kombinerer informationen, som er indhentet ved seismiske undersøgelser, med in-situ forsøg i form af "Seismic Cone Penetration Test". Herved kan de elastiske parametre fastlægges med stor nøjagtighed. Dette vil resultere i mere økonomiske funderingsløsninger idet de elastiske parametre i dag fastlægges alt for konservativt - dermed overdimensionerede fundamenter. Samtidigt forventes den nye teststrategi, at bidrage til en reduktion af det nødvendige antal in-situ målinger, hvorved den samlede omkostning til fundering af havbaserede vindmøller kan reduceres markant.

Main activities: Med projektets mål for øje vil forskningen fokusere på følgende:

- Udvikle og teste SCPTu målemetoder.
- Formulerer en metode til tolkning af SCPTu forsøgene. Tolkningen skal sikre pålidelig fastsættelse af både de elastiske og plastiske materialeparametre.
- Udvikle en metode der kan beskrives de målte parametre som stokastiske variabler og fastlægge variationen med dybden.
- Tilvejebringe tilstrækkeligt statistisk grundlag for at kunne udtale sig om variationen af materiale- parametre i horisontal retning.
- Formulering og opstilling af den sandsynlighedsbaserede teststrategi.

Dette projekt kan også gennemføres i relation til motorvejsbyggeri hvor samarbejdspartnerne vil være Vejdirektoratet.

Contact person: Lars Bo Ibsen

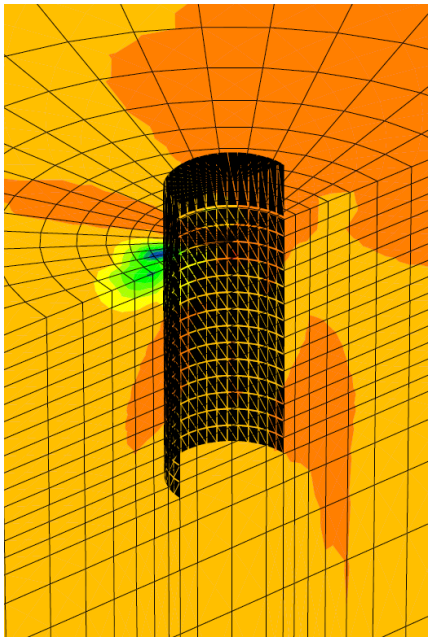
Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

Offshore Wind Turbine Foundations: Numerical evaluation of *p-y* and *p-Q* curves for piles in sand

A project in cooperation with

DONG energy

Purpose: The interactions between soil and laterally loaded piles are typically accounted for by use of *p-y* curves. A *p-y* curve defines the relationship *p*(*y*) between the soil resistance *p* arising from the non-uniform stress field surrounding the pile mobilised in response to the lateral pile displacement *y*, at any point along the pile. The *p-y* curves adopt the Winkler approach by uncoupling the response of various layers in the soil and can therefore easily include effects of non-linearity, soil layering and other soil properties.



Currently, *p-y* curves represent the state-of-the-art for design of monopiles in the offshore wind industry. However, the currently used p-y curves are clearly inadequate. Firstly, the current stiffness-formulation does not include diameter effects. This is of great importance since pile stiffness for often becomes the primary design driver for offshore wind turbine foundations. Secondly, the resistance of the pile toe is not considered in the current *p-y* methodology. Simple analytical considerations indicate that the ultimate moment resistance of a stiff monopile may increase by 25% if the pile toe resistance is included. Thus, the main emphasis of this project is to numerically evaluate diameter effects of p-y stiffness and evaluate the pile toe resistance in terms of *p-Q* curves.

Main activities:

- Develop a 3D finite element model of a monopile in PLAXIS (or ABAQUS).
- Calibrate constitutive behaviour to simulate Aalborg University Sand no. 1.
- Verify model by comparison to small-scale model tests performed in the pressure tank. (note: the scope of work does not include the model testing)
- Use numerical model to evaluate representative *p-y* and *p-Q* curves.

Contact persons: Lars Bo Ibsen, Søren P.H. Sørensen

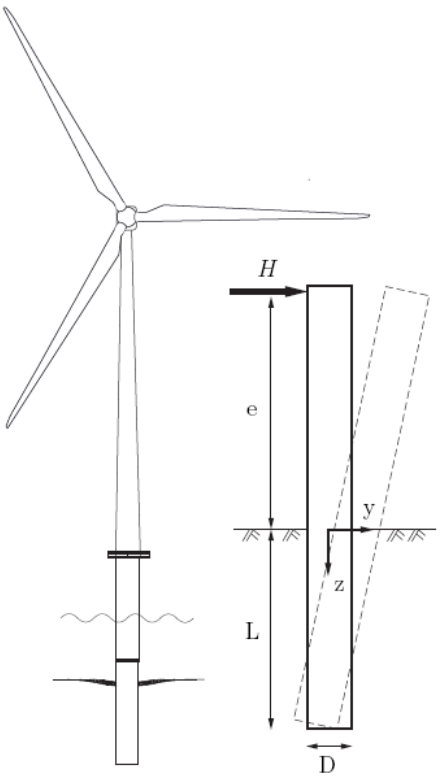
Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

Offshore Wind Turbine Foundations: Response of Stiff Piles to Long-term Cyclic Loading

A project in cooperation with

DONG energy

Purpose: There are several foundation concepts for offshore wind farms. Most current foundations are monopiles, which are stiff piles with large diameters, installed 20 m to 30 m into the seabed. The design of monopiles relies on standards and empirical data originating from the offshore oil and gas sector. However, the loading of an offshore wind turbine is very different in both magnitude and character to oil and gas installations. It is characteristic for offshore wind turbines that the sub-structure will be subjected to strong cyclic loading, originating from the wind and wave loads. This leads to accumulated rotation of the wind turbine tower, adversely affecting its ultimate strength or fatigue life. The long-term movements of the foundation may significantly impact all parts of the wind turbine, including the support structure, machine components and blades. Therefore, it is of great importance to investigate the effects of cyclic loading.



Series of laboratory tests shall be conducted using the pressure tank at AAU. The model tests must be conducted on a stiff pile installed in saturated sand and subjected to between 100 and 1000 cycles of combined moment and horizontal loading. A typical design for an offshore wind turbine monopile should be used as a basis for the study, to ensure that pile dimensions and loading ranges are realistic. A non-dimensional framework for stiff piles in sand must be applied to interpret the test results.

Main activities:

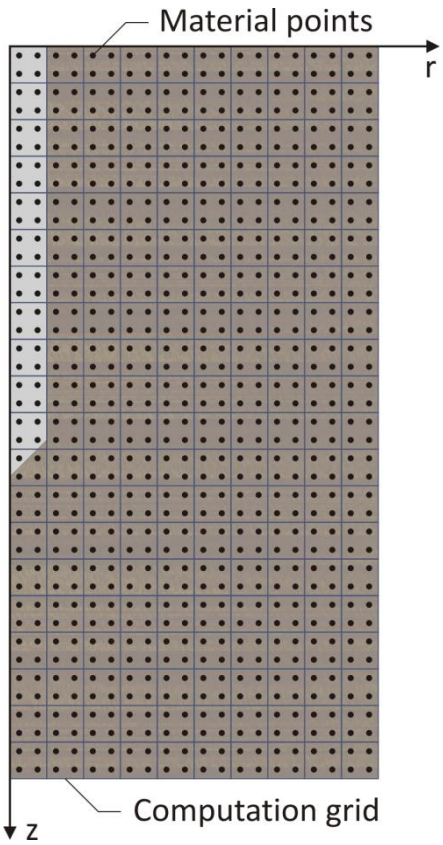
- A series of laboratory tests should be conducted on stiff piles in the pressure tank at AAU.
- Results should be used to develop methods assessing the change in stiffness and the accumulated rotation of a stiff pile due to long-term cyclic loading.

Contact persons: Lars Bo Ibsen, Søren P.H. Sørensen

Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☐☐☐

Particle-based model of pile driving and CPT

Purpose: The Material-Point Method (MPM) has emerged as a computational tool for the analysis of dynamical problems related to civil engineering. Based on continuum mechanics, the method is developed from the principle of virtual work. However, in contrast to the standard finite-element method, the integration points carrying the material properties and state variables are allowed to move through the computational grid. This is ideal for the analysis of problems involving large deformations and contact between different materials and structures. Hence, the MPM is a promising tool for simulation of geotechnical problems such as pile driving and cone penetration testing (CPT).



Recently, a PhD project has being carried out at the Department of Civil Engineering, Aalborg University, regarding the analysis of landslides by utilisation of the so-called Generalised Interpolation Material Point Method (GIMP). This method is a further development of the MPM. The idea of the project is to develop a computer code based on the GIMP for the analysis of pile driving and CPT.

Main activities: The GIMP is a relatively new method, and this project is directly related to some of the ongoing research at the university. The main activities are:

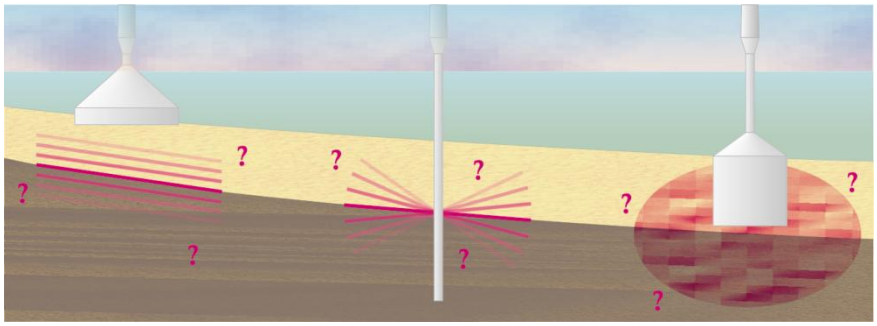
- Getting to know the MPM and the GIMP
- Formulation of the GIMP in cylindrical (axisymmetric) coordinates
- Programming the GIMP in MatLab or Fortran 95
- GIMP-analysis of CPT and/or pile driving
- Comparison of the GIMP results with experimental results.

Contact persons: Søren Mikkel Andersen, Lars Andersen

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☒

Stochastic modelling of soil

Purpose: Soil is a heterogeneous material at different levels. Thus, the ground is stratified, i.e. several soil deposits lie on top of each other, and the material within each layer is in itself heterogeneous on a local scale as seen in the figure. However, when geotechnical analysis are carried out by computational methods, soil is usually modelled as a locally homogeneous material and the position of interfaces between two different material, e.g. sand and moraine, are based on few tests. This is a huge problem because failure in the soil will always find its way through the weakest part of the material. Hence, failure figures in real heterogeneous soil may be significantly different from the ones achieved by computational analysis ... and so may the bearing capacity and deformations.



Another interesting problem is related to the dynamics of soil. Recent research indicates that even a very sophisticated model can only predict the ground vibration from metro tunnels with an accuracy of 10 to 15 dB. This means that the actual ground motion may be about four times higher than the predicted response. The main reason is believed to be the missing consideration of heterogeneity.

Main activities: The project may focus on the bearing capacity and deformations of foundations or alternatively the ground vibration from, for example, railways. In any case, the activities to be carried out may include:

- Studying the theory of soil mechanics and/or soil dynamics
- Developing models of the spatial variation of soil properties
- Creating a finite-element model for stochastic analysis of soil
- Parameter studies of bearing capacities and deformations or vibrations
- Comparison with the results of other models or tests
- Updating the design criteria for foundations.

Contact person: Lars Andersen

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☒

Design models for soil structures with geotextiles

Purpose: Geotextiles are widely used throughout the world in four main functions: Separation, filtration, drainage and protection. Fibertex is the 4th biggest producer of nonwoven geotextiles in Europe, and is situated in Aalborg East.

The current design material available for soil structures with geotextiles is very "scattered", and the purpose of the project is, through analysis and laboratory testing, to get an overview and develop new or enhance the existing design models.

Main activities: The project is relatively open with concern to the problem to be analysed. However, in any case the activities will include:

- Getting to know geotextiles
- Gathering and analysis of current design material
- Determination of focus areas
- Tests and theoretical assessment
- Computational modelling of geotextiles
- Design model creation.

Part of the project may be carried out as engineering practice, and it may be possible to perform experimental tests at the laboratory facilities of Fibertex A/S.

Contact persons: Lars Andersen, Søren Mikkel Andersen

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐

Improved FEM-modeling of non-associated plasticity

Purpose: The most common material model for soils is the Mohr-Coulomb model where the soil strength is controlled by the cohesion strength and the friction angle. The deformation during plastic flow is controlled by the dilation angle. When the model is associated, i.e. friction angle = dilation angle reliable calculation methods are abundant both in the elasto-plastic as well as the rigid-plastic case. Experimental observations, however, predicts that the dilation angle should be much lower (often ~30°) than the friction angle. Unfortunately this causes a lot of computational problems. Random errors seem to occur and simulations break down.

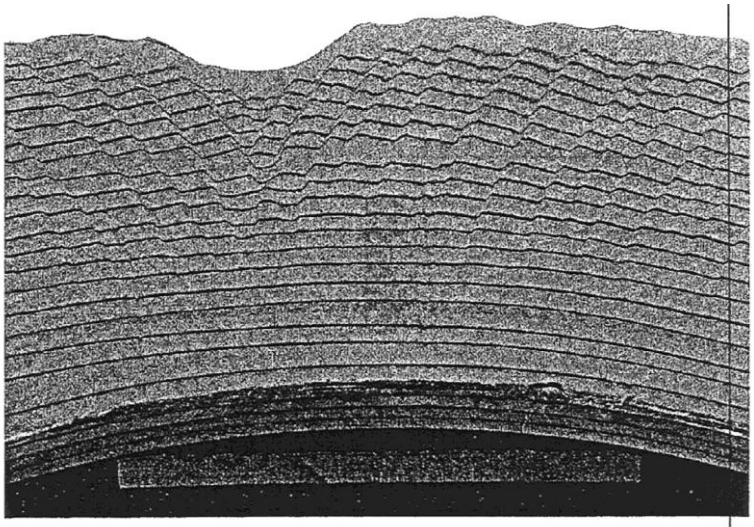


Fig. 8.2 Crestal faults over arch of uniform curvature, simulated in a sand box (Mandl, 1984).

In this project the goal is to examine how we should model non-associated soil behaviour with the finite element method. The different result of different methods could be quantified using simple benchmark calculations, e.g. a surface footing or a sheet pile wall. This project will involve a considerable amount of MatLab-programming.

Examples of main activities:

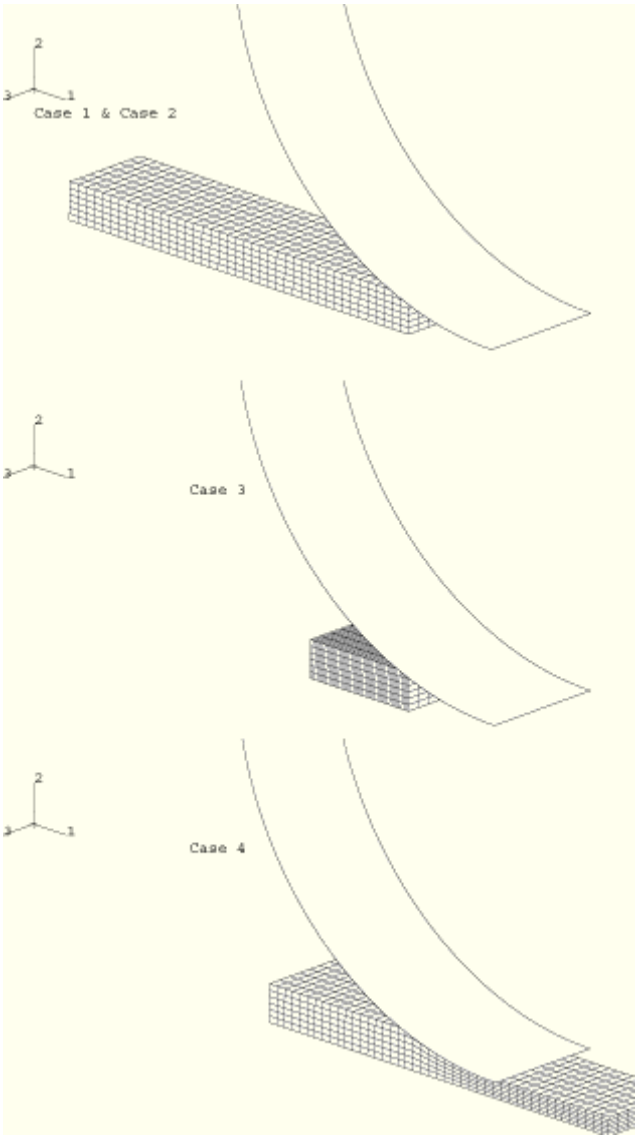
- What are the symptoms of non-associated problems? A computational and literature review.
- What do the commercial codes do (e.g. Abaqus, Plaxis, Ansys)?
- Do we have other methods of remediating the problem?
- Quantification of different results with different methods using own MatLab code
- Is a newly published critical state model the solution?

Contact person: Johan Clausen
Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

Simulation of powder compaction process

Purpose: When manufacturing cement, a powder compaction process is needed. Loose powder is displaced between to cylinders, called “rollers”, which then compact the powder into solid “cakes”. The simulation of this compaction process can be crucial in designing the machine parts and selecting settings for the most efficient compaction and least wear of machine parts. The problem of simulating the compaction process involves several non-linear phenomena, such as large strains, contact and non-linear constitutive models.

In the finite-element software Abaqus, an example is given concerning rolling of metal sheets as illustrated in the figure. The starting point of this project could be to modify this example so as to change the material model from metal into that of a powder, i.e. a granular material.



The goal of the project is to simulate the powder compaction process and possibly identify the parameters that are important in the design.

Examples of main activities:

- A literature review on powder compaction simulations.
- Determine suitable constitutive models for powder simulations.
- Modify the metal example from Abaqus in order to simulate powder.
- Detemine optimal parameters for the compaction process.
- Is it possible to design the compaction machine in a better way?

Contact persons: Lars Andersen and Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

Vibrations from railway traffic: The Femern Belt Link

Purpose: Currently the Femern Belt Link is in the project phase. In addition to the bridge or tunnel, several new road and railway structures are to be constructed as part of the link between Denmark and Germany.

Regarding the railway lines on the Danish side of the belt, new Danish regulations prescribe that the level of noise and vibrations along new railway lines must be documented in the project phase. Thus, based on in situ measurements of the dynamic properties of the soil, computational and empirical models must be applied in order to predict the vibration levels that can be expected along the planned railway line. Further, engineering solutions may be necessary along parts of the line to reduce the vibrations to an acceptable level.

Main activities: The project concerns the analysis of vibrations from trains running on the planned railway on the Danish side of the Femern Belt Link. The following items may be part of the project work:

- Literature study of wave propagation in soil and railway lines
- Numerical modelling of vibration transmission through the rails and subsoil
- Modelling of the train as a multi-degree-of-freedom system
- Design of trenches or other structures to minimise the emission of vibrations
- Design of an easy-to-use programme for evaluation of wave transmission.

The work may be carried out in collaboration with Rambøll Denmark who is the main contractor for the assessment of noise and vibrations from railway traffic on the Danish part of the Femern Belt Link.

Contact person: Lars Andersen

Theory: ☒☒☒ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐

Finite-element modelling of reinforced concrete

Purpose: Reinforced concrete is widely applied as a construction material in civil engineering. Concrete is a complex material, both chemically and mechanically, and the formulation of material models demands a deep knowledge of the behaviour during casting, curing, utilization and, eventually, degradation. The introduction of reinforcement results in a composite material. In this case the interaction between the concrete matrix and the steel reinforcement must be accounted for as well.



The idea in this project is to develop an ABAQUS model that can be applied to the finite-element analysis of reinforced concrete structures with a complex geometry, e.g. curved shells. The goal is to construct of a model that facilitates both a genuine model of the respective materials and, not least, a realistic description of the interfaces between concrete and steel. The project may focus on the analysis of a particular problem or structure.

Main activities:

- Formulation of material models for concrete
- Modelling of composite shells in ABAQUS
- Modelling of interfaces between concrete and reinforcement
- Finite-element analysis of reinforced concrete structures
- Comparison of FE models with standard design methods.

Contact persons: Lars Andersen, Eigil V. Sørensen, Christian Frier

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☒

Air permeable concrete walls

Purpose: Many modern buildings require cooling in the daytime and heating during the night. If the surplus heat produced through the activities in the building in the daytime might be efficiently stored in the building structure, and subsequently be released during the night, the energy requirement for heating and cooling might be substantially reduced. To a certain extent concrete and masonry walls of high thermal capacity are currently being used for equalizing heat loads, however not very efficiently due to a poor combination of convective heat transfer at the surface and heat conduction in the wall. Also, it is impossible to control the heat transfer.

However, by designing the wall as a permeable concrete structure permitting air transport through the material the heat transfer can be significantly enhanced and the thermal capacity of the wall can be optimally utilized. In addition, the heat transfer can be controlled via the rate and the direction of the air flow in such a "dynamic wall system"

The purpose of the proposed project is to develop a concrete material for production of load bearing, air permeable concrete walls.

Main activities: The concrete should be designed to have a workability allowing it to be soft cast at a precast concrete plant, and possibly in situ as well. It must attain a certain compressive strength, and the size distribution of the through-pores as well as the air permeability of the hardened concrete must be controllable to a certain extent. The main activities to attain the above objectives are:

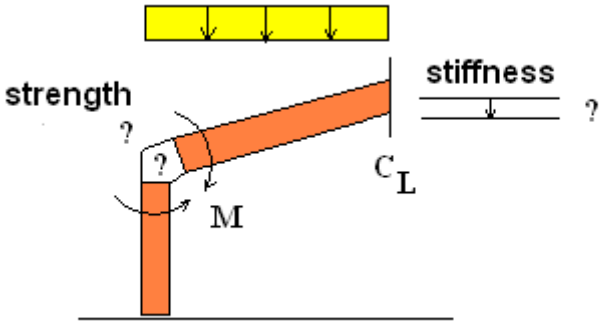
- Theoretical analysis involving particle packing and subsequent calculation of possible concrete mix designs
- Mixing and casting of specimens in the concrete laboratory
- Experimental evaluation of the pore size distribution of the concrete, measurement of the compressive strength and the air permeability.
- Development of guidelines for production of load bearing air permeable concrete walls.

Contact person: Eigil V. Sørensen

Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☐☐

The corner of laminated timber frames

Purpose: Laminated timber frames are, for instance, desirable in structures where the aesthetics of the structure is in focus. A weak point in a timber frame is the frame corner and its strength and stiffness. But perhaps the corner does not need be made of wood?



Could a reinforced concrete structure or a steel structure be employed in the corner instead? At least the drawbacks of a corner made of wood might be removed and by employing wood in the remaining part of the frame, the frame would still visually appear much like a full wooden frame.

Main activities: The aim of the project is to explore the stiffness and strength of a timber frame employing different solutions in the corner of the frame (steel and/or reinforced concrete and using the full timber frame as reference).

In the project you will develop numerical and analytical models for the various solutions and full-scale tests will be conducted aiming at verifying the strength and stiffness predicted by your models.

Should your investigations reveal that solutions with steel or reinforced concrete in the corner of the frame are feasible (in terms of strength and stiffness) it might indicate a potential for a new type of frame structures.

The project might involve co-operation with external parties having an interest in mapping the potential of alternative solutions for timber frames.

Contact persons: Lars Pedersen, Christian Frier

Theory: ☒☒☐ **Experimental work:**. ☒☒☐ **Computer modelling:** ☒☒☐

Advanced Analysis of Steel Frames

Purpose: In ultimate limit state analyses of steel frames compression forces and bending moments are of concern, as they may lead to global instability manifested in either buckling or lateral torsion failure.

The design guide Eurocode sets up procedures for evaluating the ultimate limit state and actually Eurocode (EC) suggests a number of different design approaches to choose from. Some EC-approaches are more simplifying than others, and this means that the final evaluation of the ultimate limit state depends on the method chosen for the evaluation. Or does it?

The purpose of the study is to highlight and quantify load carrying capacity of steel frames employing different methods, ranging from basic methods to more advanced methods (in all methods FE-analyses are required but to various degree of complexity).

In the initial part of the study focus will be on analysing a reference steel frame, but in order to highlight the degree of differences in calculated load carrying capacities it is useful to extend the study. This, for instance, by studying a range of steel frame configurations or to conduct some other type of parameter study focusing on sensitivity of outcome of your calculations to input assumptions related to structural modelling.

Main activities: Besides from a literature review focusing on the background for EC-guidance focus will be on

- Implementing and describing procedures
- Finite element modelling and analyses
- Parameter and sensitivity studies

so as to provide an overview of load carrying capacities of steel frames as computed using different methods.

As part of the study it might be useful also to analyse one of the steel frames which recently collapsed due to heavy snow loads.

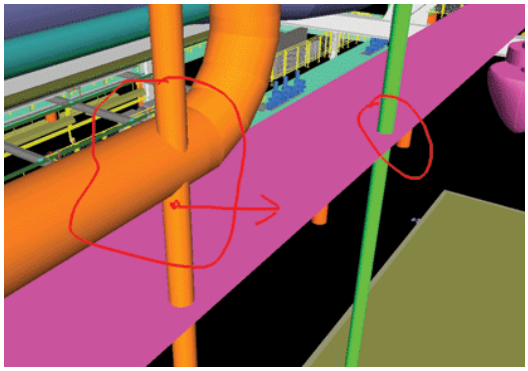
Contact persons: Lars Pedersen, Johan Clausen

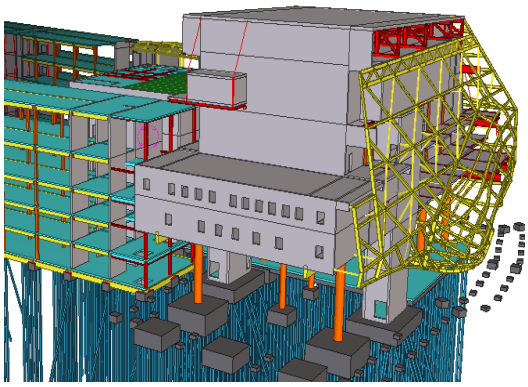
Theory: ☒☐☐ **Experimental work:**. ☐☐☐ **Computer modelling:** ☒☒☐

Structural modelling and design coordination

Purpose: The construction industry is changing from traditional CAD drawings to more intelligent 3D object based models of the entire building. There are many attempts to improve the structural design process by making a better connection between object based CAD systems and structural simulation tools. The simulation tools can be more or less integrated with specific CAD systems or they may exchange data through open international standards. An important issue for the structural engineer is also the often complicated coordination with requirements from other disciplines such as architecture, HVAC etc. New IT tools are introduced to assist this coordination.

The purpose of this project is to identify critical elements of the integrated design and coordination process and examine how new methods and information technology can assist us in the future construction industry.





Main activities:

- Identify strength and limitations in current practices and identify opportunities with upcoming technologies in the area
- Review of enabling Information and Communication technologies (ICT), including software, data models, international standards, and human computer interaction tools
- Examine today's possibilities with existing tools
- Identify needs for new ways of working and from that derive a list of requirements on technical solutions
- Demonstrate possible solutions for the near future and describe issues for future development

The work may be in collaboration with a consulting engineering company.

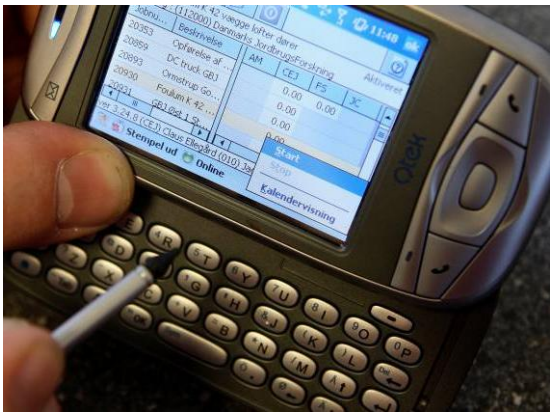
Contact persons: Kjeld Svidt, Per Christiansson

Theory: ☒☒☐ **Experimental Work:** ☒☒☐ **Computer Modelling:** ☒☒☐

Future information technology at the construction site

Purpose: In recent years, the construction industry has started changing from traditional 2D CAD drawings to more intelligent 3D object based models of the entire building. Such models give us a number of new possibilities for planning and controlling the activities at the construction site through advanced 4D models and possible links between the physical construction components and the virtual building model. New information and communication technology can improve the communication of correct instructions at the right time for the construction work as well as capturing information for quality assurance and as-built documentation.

The purpose of this project is to identify important problems within the area and propose solutions for future use of state-of-the-art information technology at the construction site.



Main activities:

- Identify current practices and problems in traditional construction projects
- Review of enabling technologies, software, hardware, international initiatives
- Test existing methods, software, hardware
- Identify needs and requirements for new solutions
- Build early prototypes with more or less functionality for initial tests

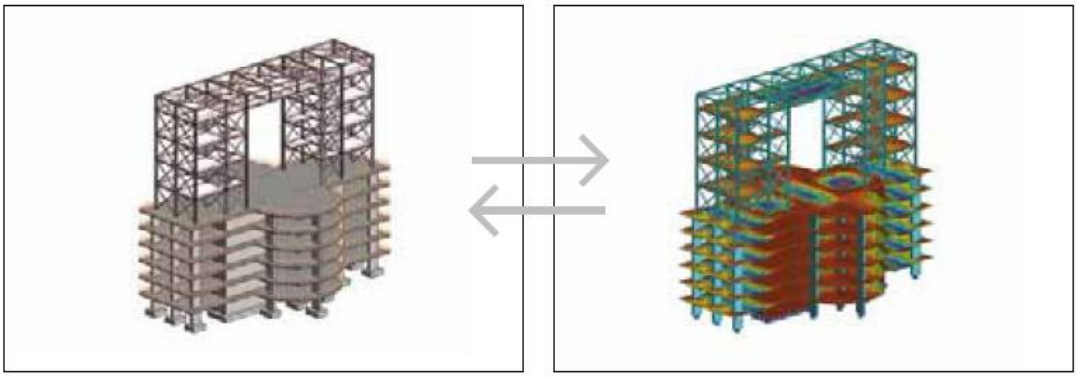
The work may be carried out in collaboration with a construction company.

Contact persons: Kjeld Svidt, Per Christiansson

Theory: ☒☒☐ **Experimental Work:** ☒☒☐ **Computer Modelling:** ☒☒☐

Structural modelling and analysis using BIM tools

Purpose: Although 2D and 3D modeling software has been used for decades to analyze and design structures, over the past few years a wave of new 3D modeling tools are allowing structural engineers and designers to create models for documentation and coordination as well. As a result, more and more structural engineering firms are embracing the Building Information Modeling (BIM) movement. BIM software is based on the object-oriented programming paradigm, in which instances of structural members are assembled to create a building structure. Each member possesses the information and functionality that fully defines it. In other words, a beam element knows its properties (e.g. material, sectional properties…), as well as its purpose within the structure (i.e. a horizontal member on level X, spanning between column Y and girder Z). The resulting BIM model contains a wealth of information which can be useful for inter-discipline coordination as well as internal coordination. Recently many add-on BIM tools have been presented which integrated the structural analysis of e.g. reinfored concrete and steel structures into the BIM framework.
The purpose of the present project is to perform an evaluation of add-on tools for structural analysis.



Main activities:

- Identify strength and limitations in current add-on BIM tools and identify opportunities with upcoming technologies in the area
- Modelling and structural analysis of different structures and comparison with theory and traditional FEM results.

The work may be in collaboration with RAMBØLL.

Contact person: Poul Henning Kirkegaard

Theory: ☒☒☐ **Experimental Work:** ☐☐☐ **Computer Modelling:** ☒☒☒

Reliability assessment of existing and temporary structures

Generally reliability requirements and partial safety factors are related to permanent structures, e.g. with a design lifetime equal to 50 years. This is for example the case in the Eurocodes. For existing structures and for temporary structures, e.g. structures during execution and structures only used for a short time interval, no design requirements can generally be found in the codes, but are highly demanded by industry.

Both for existing and temporary structures it is sometimes argued, that the reliability level could be chosen lower than for permanent structures. But is that reasonable - e.g. for structures where people can be in danger in case of failure? And if the reliability level in some cases can de lowered, how much can the partial safety factors be decreased?

For existing structures, e.g. concrete bridges, information will often be available, e.g. in the form of measured concrete compression strengths of test samples, measured traffic loads, ... How can such information be used to assess the reliability of the structure, and eventually decrease the partial safety factors?

Main activities:

- Collect information from literature on assessment of reliability of temporary and existing structures
- Assess and describe methods to obtain the minimum reliability level using risk and reliability-based principles:
    - cost-benefit analyses: minimize lifecycle total expected costs
    - LQI (Life Quality Index) principles: requirements by society
- Transformation of evt. reduced reliability level to reduced partial safety factors and/or reduced characteristic loads.
- Select one or more illustrative structures (an existing structure and/or a temporary structure), and for the selected structure(s):
    - Stochastic modelling of loads and strengths
    - Assessment of minimum reliability level to be required
    - Estimation of evt. reduced partial safety factors

Contact person: John Dalsgaard Sørensen

Theory: ☒☒☐ **Experimental Work:** ☐☐☐ **Computer Modelling:** ☒☒☐

Design for earthquakes in Denmark

During the last years some small earthquakes have been observed in or close to Denmark. The Danish rules for design of buildings and bridges do not require seismic design using Eurocode 8. The only requirement is that an accidental limit state with a so-called 'horizontal load' has to be verified. Compared with the 'old' design rules in Denmark (from the 1998 version of DS409) the requirements have been relaxed with introduction of Eurocodes. Due to the recent 'small' earthquakes observed in Denmark it has been questioned if the present Danish requirements related to the 'horizontal load' are sufficient and result in a sufficient reliability level.

In other European countries with low seismic activity it is considered to introduce the simple 'horizontal load' covering earthquake loads instead of using Eurocode 8 – but with the same reliability.

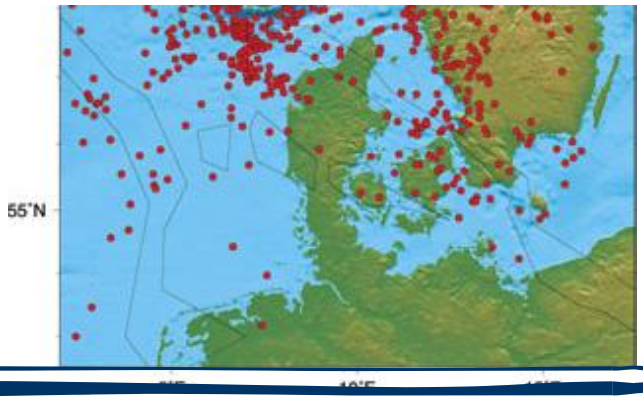
The main objective of the project is to

- Collect and analyse the observations (time histories, damages, ...) from earthquakes observed in Denmark
- Use Eurocode 8 to analyse selected typical buildings and foundations exposed to earthquake loads equivalent to the observed earthquakes
- Investigate if the present Danish requirements for earthquake design are sufficient, and if not, to propose new design rules to be submitted to the Danish Permanent Committee for 'Safety and Load', Danish Standard

Main activities:

- Collect information from literature on seismic design of structural systems, especially buildings
- Collect information on recent earthquakes in Denmark: times series and damages; and analyse the information
- Select typical buildings (in steel and concrete / low-, medium- and high-rise) and e.g. three different soil conditions
- Determine and analyse the horizontal forces for the selected buildings using Eurocode 8 and compare with the 'horizontal force' from present Danish design rules and from the old Danish design rules in DS409/410 from 1998
- If needed, propose new / modified design rules to be used in Denmark
- Formulate a background note to be used as basis for introduction of a 'horizontal load' to be used in European countries using Eurocodes but with low seismic activity.

Contact person: John Dalsgaard Sørensen
Theory: ☒☒☐
Experimental Work: ☐☐☐
Computer Modelling: ☒☒☐



Risk analysis of Wind Turbines

Wind turbines are a building / machine with many structural (tower, blades, foundation, …), mechanical (gearbox, bearings, …) and electrical (generator, …) components. The complete wind turbine is a complicated system where failure of some of the components can have serious consequences. Failure of a component can not only be critical for the wind turbine itself but also for the environment. The consequences for the environment can be loss of electricity supply which is serious if the supply from a complete offshore wind farm is lost. Another consequence in case of full or partial failure of e.g. a wind turbine blade is that people, buildings, etc. can be hit by a part from the wind turbine thrown several hundred meters away. In case of wind turbine icing also the risk of ice-fragments thrown away from the blades can be important.

The purpose of this project is to establish an overview of risks associated with wind turbine failures and icing. This includes description of failure modes, failure rates and consequences. Further to describe a methodology to assess these risks quantitatively and how to establish acceptable risks.

Main activities:

- Literature survey to give an overview of risks associated with wind turbine failures and icing:
    - failure modes
    - failure rates
    - consequences
- Use principles from risk analysis to describe a methodology to assess
    - Risks related to the wind turbine itself
    - Risks related to the environment
    - What are the acceptable risks?
- Selection of representative part of the whole wind turbine system and implementation in a computer program using existing algorithms
- Illustrative example studies

The project can be made in cooperation with an external partner

Contact person: John Dalsgaard Sørensen
Theory: ☒☒☐ **Experimental Work:** ☐☐☐ **Computer Modelling:** ☒☒☐



Collapse of wind turbine at Djursland, February 2008 – wind turbine parts thrown up to 400 m away!

Load Extrapolation for Wind Turbines during Operation

Description: For wind turbines the largest loads can often occur during operation where the wind turbine is producing power. Methods for estimating the extreme load in these cases are often inadequate and subjected to significant uncertainties. Therefore new and better methods along with a more thorough understanding of the response at high load levels for wind turbines are needed.

The present project focuses on two main topics:

- Compare the existing methods for simulated data and field measurements
- Developing new methods for load extrapolation

The existing methods should be compared for a representative wind turbine in order to estimate the variation between the different methods. However, the load extrapolation is normally performed using only the largest responses which are subjected to significant model and statistical uncertainty. Therefore, measurements on a wind turbine will also be used in order to reduce the model uncertainty related to the aeroelastic simulations.

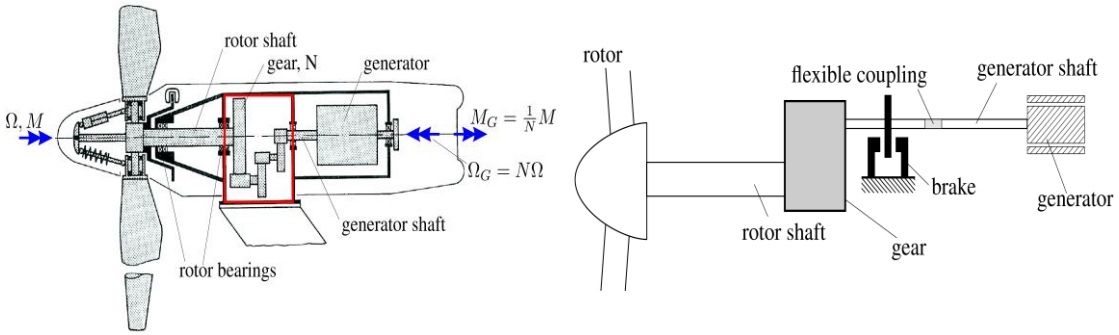
Based on the knowledge obtained through the comparison of the existing methods will pro and cons for individual methods be identified and this information will be used in the developing of new and better models. The new models should also be applicable to offshore wind turbines where additional environmental loads such as wave loading should be taken into account.

Contact persons: Henrik Stensgaard Toft, John Dalsgaard Sørensen

Theory: ☒☒☐ Experimental work: ☐☐☐ Computer modelling: ☒☒☐

Estimation of Low Failure Probabilities of Wind Turbines

Purpose: Estimation of low failure probability of wind turbines is typically done by assuming the epochal extremes in a 10 minute interval are distributed according to some asymptotic extreme value distribution and extrapolating the results to 50 years. In this regard parameters of the distribution function are needed to be estimated via numerical simulations.



a) **b)**

Unfortunately conventional Monte Carlo simulation is not an efficient way of estimating low probability events. To circumvent this problem variance reduction Monte Carlo methods such as importance sampling or splitting methods might be considered alternatively. Some of these methods break down at large dimensional problems. In the project a rather new simulation method based on the evolution of the probability density functions are applied. The method breaks down the multi-dimensional problem into a series of independent scalar problems and it also has bearing on other structural systems than wind turbines. The aim of this project is to implement the variance reduction methods into an aero elastic code (FAST) on a simulated wind turbine model.

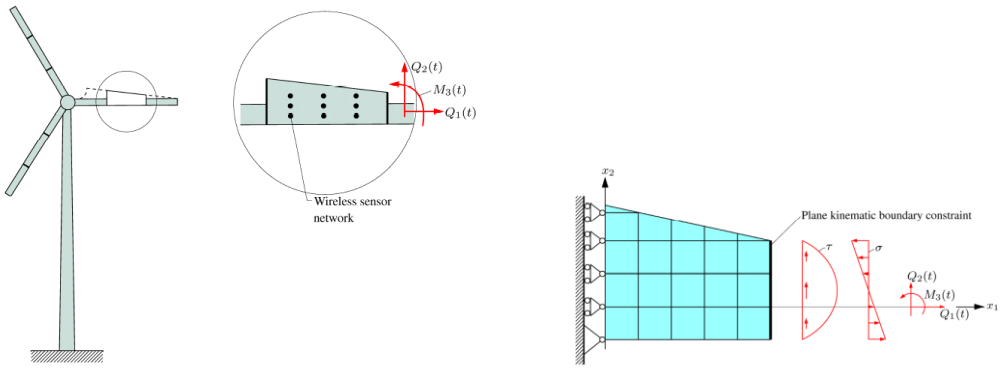
Main activities:

- Getting knowledge of the considered variance reduction methods.
- Estimating the failure probability of a simplified 5DOF model of a wind turbine.
- Compare results with crude Monte Carlo simulation

Contact persons: Søren R.K. Nielsen, Mahdi Teimouri Sichani

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

Micro-macro Modeling of Wind Turbines



Purpose: In the project an initial analysis is performed of the wind turbine by means of a flexible multibody program, in casu either the ADAMS or the MECANO commercial program. The blades are modeled by advanced beam models taking the effect of the interaction of shear, elastic and mass centers and the centrifugal stiffening into consideration, as well as the pre-twist and pitching of the blades. The output of the program is the section forces and moments at each node along the blade. This part of the project makes up the macro modeling, which in principle does not involve any individual programming. Next, a part of the blade of the length 2-3 profile chords is taking out for detailed modeling in order to test for local stresses. The modeling is based on shell models (thin plate or Mindlin shell theory) for surface (skin) and internal webs. The modeling section is fixed to a vertical wall at the one end section, and is free at the other. At the free end kinematic constraints are imposed to insure that plane section remain plane to fit the conditions of the kinematic adjacent beam elements. The section forces and bending moments calculated from the macro-modeling are next applied in agreement with the Navier and Grashof stress distributions. This part of the modeling makes up the micro modeling. Here, a certain additional programming is necessary to introduce the gyroscopic inertial loads in the model.

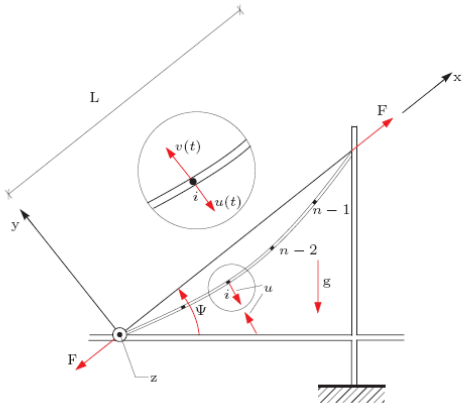
Main activities:

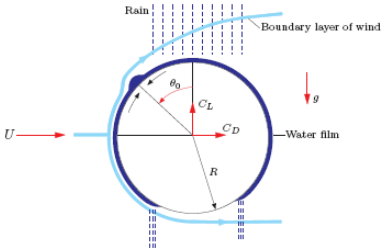
- Getting to know the MBS method (FEM method)
- Comparing results of different methods on a simulated wind turbine.

Contact person: Søren R.K. Nielsen, Phasad Chougule, Poul Henning Kirkegaard

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

Nonlinear Optimal Vibration Control of Stays in Cable Stay Bridges





Purpose: Rain-wind induced vibrations of cables in stayed bridges is an aeroelastic instability phenomena caused by local thickening in terms of so-called rivulets of the water film on the surface of the cable. The vibrations are extremely large with a double amplitude of up to 10-15 cable diameters. The phenomena takes place at wind velocities of the magnitude 13-15 m/s, and may consequently happen rather often during the life time of the bridge. The driving mechanism is quite similar to galloping vibrations of icy electric transmission line. The difference is that the shape of the asymmetric cross-section in the present case is changing with time, because the rivulets is performing vibrations relative to the moving cable, driven by the accelerations of the cable. The vibrations are controlled by a non-analytical non-linear damping term. In praxis rain-wind induced vibrations are counteracted by linear viscous dampers placed close to the lower support of the cable at the bridge deck. Passive, linear viscous dampers can only be tuned to optimal performance for vibrations in a single mode. However, field observations show that many modes may be excited at the same time, so a multi-modal vibration control is needed. In this respect an optimal active vibration controller is designed in the project, taking the non-linear motion of the rivulets in consideration. The performance index is taken as a positive quadratic functional of the state vector of the cable response and the active control force (so-called non-linear QR control). The minimization of this performance index insures minimum cable vibrations with a minimum of control effort. The obtained controller is compared with that of a the linear viscous damper, and with other active control strategies.

Main activities:

- Knowledge of vibration control methods
- Developing an implementation for a simple cable structure

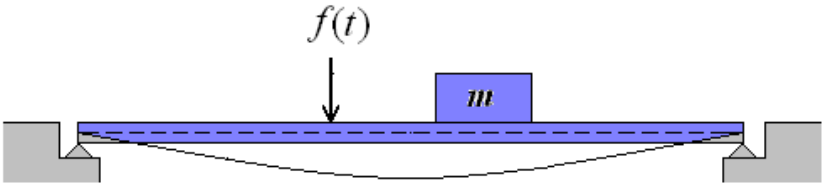
Contact persons: Søren R.K. Nielsen, Poul Henning Kirkegaard

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐

Dynamic human-structure interaction

Background: In static calculus, passive (sitting/standing) humans are modelled as a rigid mass attached to the structure. In dynamics, humans in motion (people walking or jumping) are modelled as a dynamic load bringing the supporting structure into vibration.

Human in motion Passive person



In assessments of vibration levels of slender structures carrying humans (such as footbridges, stadia-structures, or office floors) these models are conventionally employed. But are they reasonable?

Purpose: The aim of the project is to study mechanisms of human-structure interaction focusing on areas where the models mentioned above are inadequate. Prior to codifying new models describing the phenomena, they need to be properly researched.

In the project you will plan and conduct experiments striving to highlight the true mechanisms of human-structure interaction on slender structures. Measured vibration data will allow you to calibrate alternative models of the interaction accounting for the flaws in existing models.

Implications of findings (new models of the interaction) you may illustrate through computer simulations of structural response to the dynamic loads generated by humans.

Contact person: Lars Pedersen

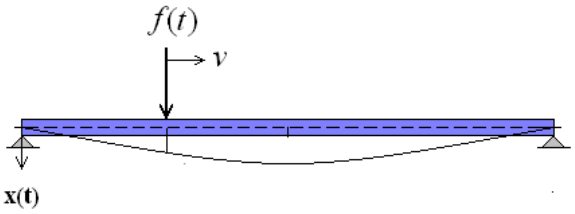
Theory: ☒☐☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

Dynamic human loading and stochastic models for estimating structural responses

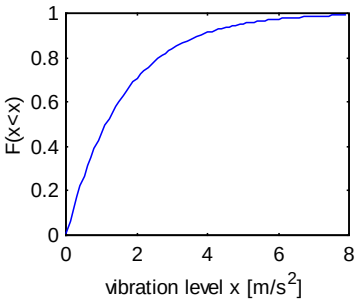
Background: Some civil structures are so slender that their modes of vibration may be excited by the basic frequency of human motion resulting in resonant structural action. The undesired resonant action may for instance occur in footbridges, stadia structures or in open-space office floors as a result of walking or jumping.

Codes and standards handle the phenomenon semi-empirically or even fully deterministic although fundamentally the loading generated by humans in motion is stochastic.

Purpose: The aim of the project is to develop and test stochastic models describing the loading and the structural response. An essential contribution would be to derive statistical distributions of structural responses to human-induced loading, as this would provide valuable information for assessing structural safety or serviceability. Specifically, the risk of exceeding various vibration levels is of interest although it is actually a parameter not given much/any focus in existing design codes.



Walking load when v > 0 m/s, ”Jumping load ” when v = 0 m/s



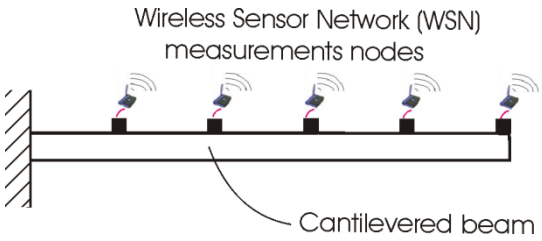
Statistical distribution of response

Through the project you will learn how to model the dynamic excitation of humans in motion, deterministically as well as stochastically. You will conduct parametric studies and numerical simulations to highlight essential implications of stochastic modelling of the phenomenon. Experimental verification of models is a possibility if so desired.

Contact persons: Lars Pedersen, Christian Frier

Theory: ☒☐☐ **Experimental works:** ☐☐☐ **Computer modelling:** ☒☒☒
(The amount of experimental work can be decided during the project)

System Identification in Civil engineering Structures using Smart Sensors



Purpose: Smart sensor technology based on wireless sensing has seen substantial advance during recent years. Each sensor in the array consists of a sensor, typically a piezo electric sensor, and a chip, which may communicate with other sensor, and which is able to perform calculations, here system identification, on its own data or data from the neighboring sensors.

In the project a small wireless sensor array made up of 5 sensor nodes is devised on a clamped horizontal beam, which is activated by vertical accelerations of its support point. The sensor system is bought from a commercial company. The aim of the project is to get it to work and to estimate lowest few modal parameters of the beam (eigenfrequencies, modal damping ratios, mode shapes).

Thre project involves a shorte stay at Trinity College, Dublin, for training in smart sensor technology

Main activities:

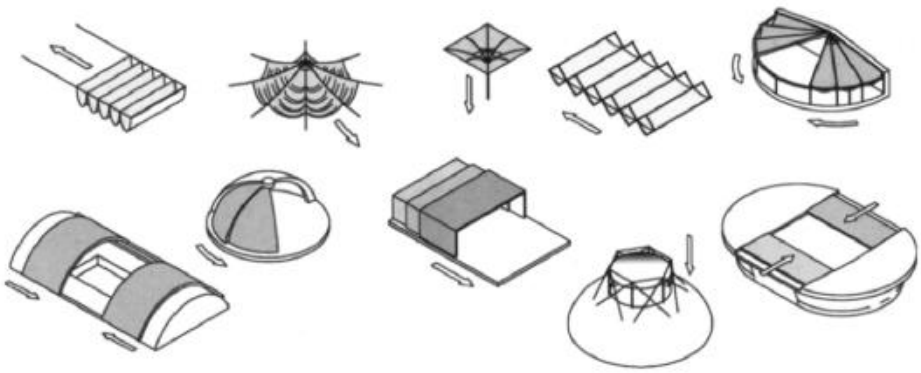
- Getting knowledge smart sensor methods
- Knowledge of system identification methods
- Knowledge of sensor location methods
- Developing an implementation for a simple structure

Contact persons: Søren R.K. Nielsen, Nevena Perisic, Poul Henning Kirkegaard

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

Multibody dynamics and control of flexible kinetic structures

Purpose: The project will consider the behaviour and approaches to the design of so-called kinetic structures, i.e. structures that can be moved after assembly (or move by themselves by means of built-in motors) from a "fully closed" or compacted configuration to a "fully deployed" one, in which the structure features its functionality, and vice-versa.



In particular, the final aim will be to establish the feasibility of implementing active, semi-active or passive control techniques both during deployment and in the deployed configuration. An actively controlled deployable structure belongs to the class of "Smart Structures". Smart structures concepts have been developed since relatively long time in aeronautics, astronautics and in robotic mechanics, where the use of electronic devices and innovative materials has been traditionally very intensive because of their fundamental importance. In the structural engineering field, smart structures concepts and namely active control techniques have been introduced very recently and apart from a very limited number of real- world applications are mainly a subject of research, compared for instance to other innovative techniques for the reduction of vibrations in buildings.

For the analysis of the flexible kinetic structure the multibody system (MBS) method and a time-variant system control method will be considered.

Main activities: The project will be related to ongoing research at the university where the MBS method is used related to wind turbines and kinetic structures. The main activities in the project will be:

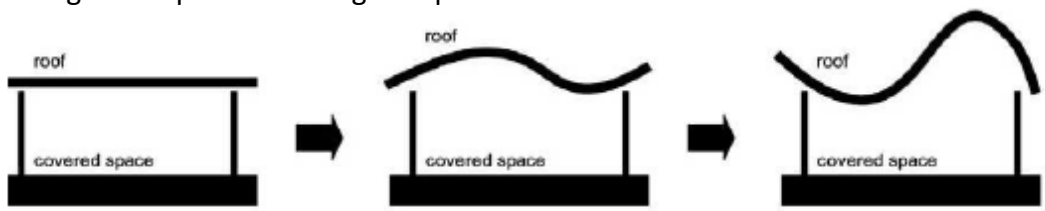
- Getting to know the MBS method (FEM method)
- Getting to know active, semi-active and passive control methods
- MBS modelling of a kinetic structure and implementation of a control method.

Contact persons: Poul Henning Kirkegaard, Søren R.K. Nielsen

Theory: ☒☒☒ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

MBS modelling of kinetic structures

Purpose: Kinetic structures follows a new trend emerging in architecture related to the physical movement of structural building elements that can result to the spatial movement of a structure as an entirety or just part of it. More particularly, this kind of architecture can be defined as: Buildings and/or building components with variable mobility, location and/or geometry. Structural solutions must be considered in parallel both the *ways* and *means* for kinetic operability. The *ways* in which a kinetic structural solution performs may include among others, folding, sliding, expanding, and transforming in both size and shape. Shape control within architectural kinetic structures is a natural extension to the practice of engineering and architectural design. Structural shape control is of major interest within responsive architecture because it is the primary ingredient needed to produce building envelopes that change shape.



Developing of responsive kinetic architecture requires that one could simulate such a mechatonic system as a multibody system (MBS) combined with a shape control method.

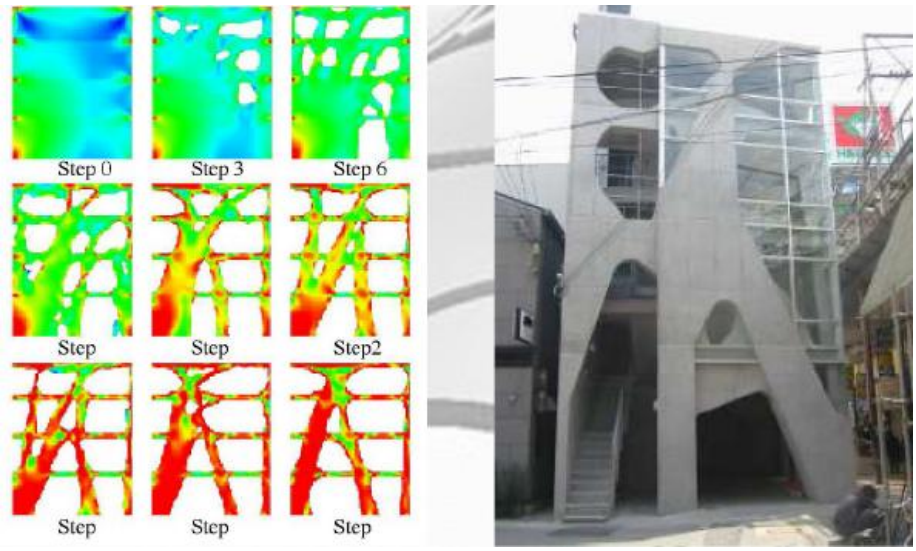
Main activities: The project will be related to ongoing research at the university where the MBS method is used related to wind turbines and kinetic structures. The main activities in the project will be:

- Getting to know the MBS method (FEM method)
- Getting to know shape control methods
- MBS modelling of a kinetic structure using the software packages ADAMS and Simulink.

Contact persons: Poul Henning Kirkegaard, Søren R.K. Nielsen

Theory: ☒☒☒ Experimental work: ☐☐☐ Computer modelling: ☒☒☒

Structural Design using Structural Optimization



Purpose: In the last few years a number of computational methods have been developed for structural optimization, methods for structural shape optimizationor for topology optimization like evolutionary structural optimization methods (ESO / Extended ESO). Most of these methods are based on dissecting the element into numerous parts for the optimization process and by deleting or adding parts after individually being tested against the design objective, which is achieved by variation of the design variables who are subjected to the design constraints in a process of multiple iterations. Over the past two decades there has been an increasing interest in using what has come to be called Evolutionary Computation (EC) in the analysis and optimization of structural systems. These methods include Genetic Algorithms (GA), Evolution Strategies (ES), Simulated Annealing and other stochastic based numerical methods. Each of these methods shares the drawback that they are very computationally intensive compared to deterministic methods. Furthermore, the computational burden can rapidly increase as the size of the analyzed structure increases. This project will consider how shape and topology optimization methods can be used for structural design.

Main activities:

- Knowledge of shape an topology optimization methods in civil engineering
- Evaluating the FEM program OptiStruct
- Comparative case studies evaluating a broader range of good solutions

Contact person: Poul Henning Kirkegaard, Lars Andersen

Theory: ☒☒☐ **Experimental Work:** ☐☐☐ **Computer Modelling:** ☒☒☒

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